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Title: NOVEL POLYMERS AND PHOTORESIST COMPOSITIONS
COMPRISING SAME

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NOVEL POLYMERS AND PHOTORESIST COMPOSITIONS COMPRISING SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to new polymers that contain units of fused carbonate groups and/or a lactone provided by a monomer having a ring oxygen adjacent to the monomer vinyl group. Polymers of the invention are highly useful as a resin component for photoresist compositions, particularly chemically-amplified positive-acting resists that can be effectively imaged at short wavelengths such as sub-200 nm, particularly 193 nm.

2. Background

Photoresists are photosensitive films used for transfer of images to a substrate. A coating layer of a photoresist is formed on a substrate and the photoresist layer is then exposed through a photomask to a source of activating radiation. The photomask has areas that are opaque to activating radiation and other areas that are transparent to activating radiation. Exposure to activating radiation provides a photoinduced chemical transformation of the photoresist coating to thereby transfer the pattern of the photomask to the photoresist-coated substrate. Following exposure, the photoresist is developed to provide a relief image that permits selective processing of a substrate.

A photoresist can be either positive-acting or negative-acting. For most negative-acting photoresists, those coating layer portions that are exposed to activating radiation polymerize or crosslink in a reaction between a photoactive compound and polymerizable reagents of the photoresist composition. Consequently, the exposed coating portions are rendered less soluble in a developer solution than unexposed portions. For a positive-acting photoresist, exposed portions are rendered more soluble in a developer solution while areas not exposed remain comparatively less developer soluble. Photoresist

compositions are described in Deforest, Photoresist Materials and Processes, McGraw Hill Book Company, New York, ch. 2, 1975 and by Moreau, Semiconductor Lithography, Principles, Practices and Materials, Plenum Press, New York, ch. 2 and 4.

5 More recently, chemically-amplified-type resists have been increasingly employed, particularly for formation of sub-micron images and other high performance applications. Such photoresists may be negative-acting or positive-acting and generally include many crosslinking events (in the case of a negative-acting resist) or deprotection reactions (in the case of a positive-acting resist) per unit of photogenerated acid. In the
10 case of positive chemically-amplified resists, certain cationic photoinitiators have been used to induce cleavage of certain "blocking" groups pendant from a photoresist binder, or cleavage of certain groups that comprise a photoresist binder backbone. See, for example, U.S. Patents Nos. 5,075,199; 4,968,581; 4,883,740; 4,810,613; and 4,491,628, and Canadian Patent Application 2,001,384. Upon cleavage of the blocking group
15 through exposure of a coating layer of such a resist, a polar functional group is formed, e.g., carboxyl or imide, which results in different solubility characteristics in exposed and unexposed areas of the resist coating layer. See also R.D. Allen et al., Proceedings of SPIE, 2724:334-343 (1996); and P. Trefonas et al. Proceedings of the 11th International Conference on Photopolymers (Soc. Of Plastics Engineers), pp 44-58 (Oct. 6, 1997).

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While currently available photoresists are suitable for many applications, current resists also can exhibit significant shortcomings, particularly in high performance applications such as formation of highly resolved sub-half micron and sub-quarter micron features.

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Consequently, interest has increased in photoresists that can be photoimaged with short wavelength radiation, including exposure radiation of about 250 nm or less, or even about 200 nm or less, such as wavelengths of about 248 nm (provided by KrF laser) or 193 nm (provided by an ArF exposure tool). See European Published Application

EP915382A2. Use of such short exposure wavelengths can enable formation of smaller features. Accordingly, a photoresist that yields well-resolved images upon 248 nm or 193 nm exposure could enable formation of extremely small (e.g. sub-0.25 μm) features that respond to constant industry demands for smaller dimension circuit patterns, e.g. to provide greater circuit density and enhanced device performance.

However, many current photoresists are generally designed for imaging at relatively higher wavelengths, such as G-line (436 nm) and I-line (365 nm) are generally unsuitable for imaging at short wavelengths such as sub-200nm. Even shorter wavelength resists, such as those effective at 248 nm exposures, also are generally unsuitable for sub-200 nm exposures, such as 193 nm imaging.

More specifically, current photoresists can be highly opaque to extremely short exposure wavelengths such as 193 nm, thereby resulting in poorly resolved images.

It thus would be desirable to have new photoresist compositions, particularly resist compositions that can be imaged at short wavelengths such as sub-200 nm exposure wavelengths, particularly 193 nm.

SUMMARY OF THE INVENTION

We have now found novel polymers and photoresist compositions that comprise the polymers as a resin binder component. The photoresist compositions of the invention can provide highly resolved relief images upon exposure to extremely short wavelengths, particularly sub-200 nm wavelengths such as 193 nm.

Polymers of the invention contain one or more 1) carbonate units (such as provided by reaction of a vinyl carbonate e.g. vinylene carbonate) and/or 2) a lactone provided by a monomer having a ring oxygen adjacent to the monomer vinyl group such as α -angelicalactone and γ -methylene- γ -butyrolactone.

Polymers of the invention also may contain an oxygen- and/or sulfur-containing heteroalicyclic ring that is preferably fused to the polymer backbone (i.e. at least two heteroalicyclic ring atoms as part of the polymer backbone). The heteroalicyclic ring has
5 one or more oxygen and/or sulfur atoms as ring members.

Preferred polymers of the invention also may contain a carbon alicyclic group (i.e. the group has all carbon ring members) that is fused to the polymer backbone, i.e. the carbon alicyclic ring has at least two carbon ring members that comprise the polymer
10 backbone. Preferred fused carbon alicyclic groups are provided by polymerization of cyclic olefin (endocyclic double bond) compounds such as optionally substituted norbornene groups.

Preferred heteroalicyclic polymer units may be substituted, e.g. by heteroalkyl
15 groups such as ethers (alkoxy) preferably having 1 to about 10 carbon atoms, alkylthio preferably having 1 to about 10 carbon atoms, alkylsulfinyl preferably 1 to about 10 carbon atoms, alkylsulfonyl preferably having 1 to about 10 carbon atoms, and the like. It has been surprising found that such substituents can provide enhanced lithographic results, particularly enhanced substrate adhesion.

20

For use in photoresist compositions, polymers of the invention also will contain one or more units that comprise photoacid-labile moieties. The photoacid-labile group may be a substituent of one or more of the above-mentioned units, such as a substituent of a polymerized vinyl alicyclic ether, vinyl alicyclic thioether or carbon alicyclic group.
25 The photoacid labile moiety also may be present as an additional polymer unit, e.g. as a polymerized alkyl acrylate or alkylmethacrylate, particularly an acrylate having an alicyclic moiety such as methyladamantyl acrylate or methyladamantyl methacrylate. Preferred alicyclic photoacid-labile moieties are tertiary ester alicyclic hydrocarbon groups that have two or more fused or bridged rings. Preferred tertiary ester groups

include optionally substituted adamantyl, particularly methyl adamantyl as mentioned above; optionally substituted fencyl groups, particularly ethyl fencyl; optionally substituted pinanyl; and optionally substituted tricyclo decanyl, particularly an alkyl-substituted tricyclo decanyl such as 8-ethyl-8-tricyclodecanyl e.g. as provided by
5 polymerization of 8-ethyl-8-tricyclodecanyl acrylate and 8-ethyl-8-tricyclodecanyl methacrylate. Additional alicyclic ester groups also will be suitable, including additional bicyclic, tricyclic and other polycyclic moieties.

Polymers of the invention also may contain units in addition to the above groups.
10 For example, polymers of the invention also may contain nitrile units such as provided by polymerization of methacrylonitrile and acrylonitrile. Additional contrast enhancing groups also may be present in polymers of the invention, such as groups provided by polymerization of methacrylic acid, acrylic acid, and such acids protected as photoacid labile esters, e.g. as provided by reaction of ethoxyethyl methacrylate, t-butoxy
15 methacrylate, t-butylmethacrylate and the like.

Generally preferred polymers of the invention contain 3, 4 or 5 distinct repeat units, i.e. preferred are terpolymers, tetrapolymers and pentapolymers that contain one or more heteroalicyclic groups as disclosed herein.

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Particularly preferred polymers of the invention include:

1) a polymer that contains distinct repeat units of i) a carbonate and/or lactone as discussed above; ii) maleic anhydride; and iii) an acrylate or methacrylate including those that contain a photoacid-labile group such as t-butylacrylate,
25 adamantylacrylate and the like;

2) a polymer that contains distinct repeat units of i) a carbonate and/or lactone as discussed above; ii) maleic anhydride; and iii) a vinyl alicyclic, including carbon alicyclics and heteroalicyclics as discussed above;

3) a polymer that contains distinct repeat units of i) a carbonate and/or lactone as discussed above; ii) maleic anhydride; and iii) a vinyl alicyclic, including carbon alicyclics and heteroalicyclics as discussed above; and

5 4) a polymer that contains distinct repeat units of i) a carbonate and/or lactone as discussed above; ii) maleic anhydride; iii) a vinyl alicyclic, including carbon alicyclics and heteroalicyclics as discussed above; and iv) an acrylate or methacrylate including those that contain a photoacid-labile group such as t-butylacrylate, adamantylacrylate and the like.

10 Polymers of the invention are preferably employed in photoresists imaged at 193 nm, and thus preferably will be substantially free of any phenyl or other aromatic groups. For example, preferred polymers contain less than about 5 mole percent aromatic groups, more preferably less than about 1 or 2 mole percent aromatic groups, more preferably less than about 0.1, 0.02, 0.04 and 0.08 mole percent aromatic groups and still more
15 preferably less than about 0.01 mole percent aromatic groups. Particularly preferred polymers are completely free of aromatic groups. Aromatic groups can be highly absorbing of sub-200 nm radiation and thus are undesirable for polymers used in photoresists imaged with such short wavelength radiation.

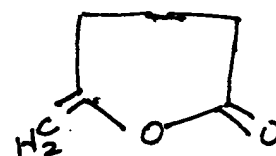
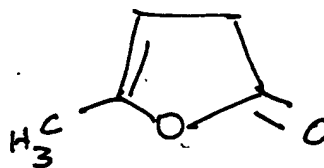
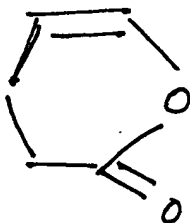
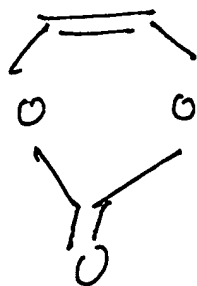
20 Polymers of the invention also may be suitably employed in resists used for imaging at other wavelengths such as sub-300 nm and sub-170 nm, particularly 2248 nm and 157 nm. Polymers employed in resists imaged at 248 nm suitably may contain aromatic groups, including phenyl groups particularly phenolic groups as may be provided by reaction of the corresponding vinyl monomer (e.g. vinylphenol). Polymers
25 employed in resists imaged at 157 nm suitably have halogen substitution, particularly fluorine substitution such as may be provided by co-polymerization of a fluoro-olefin, e.g. tetrafluoroethylene.

The invention also provides methods for forming relief images, including methods for forming a highly resolved relief image such as a pattern of lines where each line has essentially vertical sidewalls and a line width of about 0.40 microns or less, and even a width of about 0.25, 0.20 or 0.16 microns or less. The invention further provides articles of manufacture comprising substrates such as a microelectronic wafer substrate or liquid crystal display or other flat panel display substrate having coated thereon a polymer, photoresist or resist relief image of the invention. Other aspects of the invention are disclosed infra.

DETAILED DESCRIPTION OF THE INVENTION

As discussed above, polymers of the invention contain one or more 1) carbonate units and/or 2) a lactone provided by a monomer having a ring oxygen adjacent to the monomer vinyl group.

Exemplary monomers that may be employed to provide such monomers include the following:



As also discussed above, polymers of the invention may contain other units. Preferred polymers of the invention may contain additional (i.e. distinct from the carbonate and/or lactone) heteroalicyclic rings that are preferably fused to a polymer backbone. The fused heterocyclic ring units contain one or more oxygen and/or sulfur atoms. By stating herein that a cyclic group is fused to a polymer backbone, it is meant that two ring members of the cyclic group, typically two adjacent carbon atoms of the cyclic group, are also part of the polymer backbone. Such a fused ring can be provided by polymerizing a cyclic monomer that has an endocyclic double bond.

Additional preferred polymer units are polymerized carbon alicyclic compounds such as optionally substituted norbornene. As referred to herein, the term "carbon alicyclic group" means each ring member of the non-aromatic group is carbon. The carbon alicyclic group can have one or more endocyclic carbon-carbon double bonds, provided the ring is not aromatic.

Preferred polymers of the invention will contain at least about 2 to 5 mole percent of fused heteroalicyclic units based on total units of the polymer; more preferably from about 5 to 50 mole percent of fused heteroalicyclic units based on total units of the polymer; still more preferably from about 5 or 10 to about 40 or 50 percent of fused heteroalicyclic units based on total units of the polymer.

Preferred polymers of the invention will contain at least about 2 to 5 mole percent of carbon alicyclic units based on total units of the polymer; more preferably from about 5 to 50 mole percent of fused carbon alicyclic units based on total units of the polymer; still more preferably from about 5 or 10 to about 25 or 30 percent of fused carbon alicyclic units based on total units of the polymer.

In polymers of the invention that contain only heteroalicyclic units and carbon alicyclic units, preferably the heterocyclic units will be present in an amount of from about 5 to about 90 or 95 mole percent based on total polymer units, and the carbon alicyclic units will be present in an amount of from about 5 to about 90 or 95 mole percent based on total polymer units.

In polymers of the invention that consist of heteroalicyclic units, carbon alicyclic units and maleic anhydride units (i.e. carbonate or lactone:carbon alicyclic:maleic anhydride terpolymers), preferably the carbonate and/or lactone units will be present in an amount of from about 5 to about 10, 20, 30, 40, 50, 60, 70 or 80 mole percent based on total polymer units, the carbon alicyclic units (such as optionally substituted norbornene) will be present in an amount of from about 5 to about 10, 20, 30, 40, 50, 60, 70 or 80 mole percent based on total polymer units, and the maleic anhydride units will be present from about 5 to about 20, 30, 40 or 50 mole percent based on total polymer units; and more preferably the carbonate and/or lactone units will be present in an amount of from about 5 to about 10, 20, 30, 40, 50 or 60 mole percent based on total polymer units, the carbon alicyclic units will be present in an amount of from about 5 to about 10, 20, 30, 40, 50 or 60 mole percent based on total polymer units, and the maleic anhydride units will be present from about 5 to about 10, 15, 20, 25, 30, 40, or 50 mole percent based on total polymer units. In such terpolymers, suitably the carbon alicyclic units will contain a photoacid labile substituents such as a photoacid-labile ester substituent.

In any event, polymers of the invention preferably comprise contain one or more repeat units that comprise a photoacid-labile group. The photoacid-labile may be suitably a substituent of a carbon alicyclic ring member (norbornene) or, alternatively and generally preferred, the photoacid-labile moiety will be a polymer repeat unit distinct from repeat units containing an alicyclic group and may be e.g. a polymerized acrylate or methacrylate group.

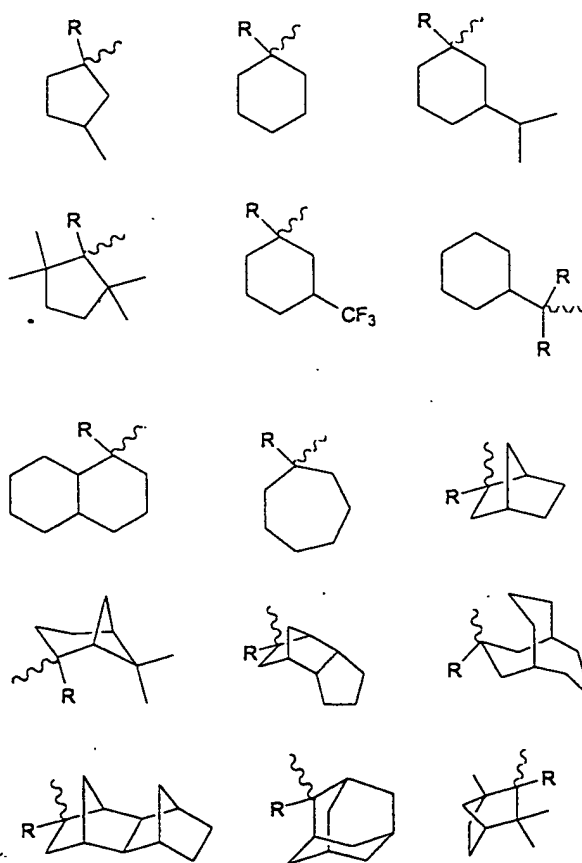
Preferred photoacid-labile groups are ester groups, particularly esters that contain a tertiary alicyclic hydrocarbon ester moiety. Preferred tertiary alicyclic hydrocarbon ester moieties are polycyclic groups such as adamantyl, ethylfencyl or a tricyclo decanyl moiety. References herein to a "tertiary alicyclic ester group" or other similar term indicate that a tertiary alicyclic ring carbon is covalently linked to the ester oxygen, i.e. $-C(=O)O-TR'$ where T is a tertiary ring carbon of alicyclic group R'. In at least many cases, preferably a tertiary ring carbon of the alicyclic moiety will be covalently linked to the ester oxygen, such as exemplified by the below-depicted specifically preferred polymers. However, the tertiary carbon linked to the ester oxygen also can be exocyclic to the alicyclic ring, typically where the alicyclic ring is one of the substituents of the exocyclic tertiary carbon. Typically, the tertiary carbon linked to the ester oxygen will be substituted by the alicyclic ring itself, and/or one, two or three alkyl groups having 1 to about 12 carbons, more typically 1 to about 8 carbons, even more typically 1, 2, 3 or 4 carbons. The alicyclic group also preferably will not contain aromatic substitution. The alicyclic groups may be suitably monocyclic, or polycyclic, particularly bicyclic or tricyclic groups.

Preferred alicyclic moieties (e.g. group TR' of $-C(=O)O-TR'$) of photoacid labile ester groups of polymers of the invention have rather large volume. It has been found that such bulky alicyclic groups can provide enhanced resolution when used in copolymers of the invention.

More particularly, preferred alicyclic groups of photoacid labile ester groups will have a molecular volume of at least about 125 or about 130 Å³, more preferably a molecular volume of at least about 135, 140, 150, 155, 160, 165, 170, 175, 180, 185, 190, 195, or 200 Å³. Alicyclic groups larger than about 220 or 250 Å³ may be less preferred, in at least some applications. References herein to molecular volumes designate volumetric size as determined by standard computer modeling, which provides optimized chemical bond lengths and angles. A preferred computer program for determining

molecular volume as referred to herein is Alchemy 2000, available from Tripos. For a further discussion of computer-based determination of molecular size, see T Omote et al, *Polymers for Advanced Technologies*, volume 4, pp. 277-287.

- 5 Particularly preferred tertiary alicyclic groups of photoacid-labile units include the following, where the wavy line depicts a bond to the carboxyl oxygen of the ester group, and R is suitably optionally substituted alkyl, particularly C₁₋₈ alkyl such as methyl, ethyl, etc.



Polymers of the invention also may contain photoacid-labile groups that do not contain an alicyclic moiety. For example, polymers of the invention may contain photoacid-labile ester units, such as a photoacid-labile alkyl ester. Generally, the

carboxyl oxygen (i.e. the carboxyl oxygen as underlined as follows: $\text{-C(=O)\underline{O}}$) of the photoacid-labile ester will be covalently linked to the quaternary carbon. Branched photoacid-labile esters are generally preferred such as t-butyl and $\text{-C(CH}_3)_2\text{CH(CH}_3)_2$.

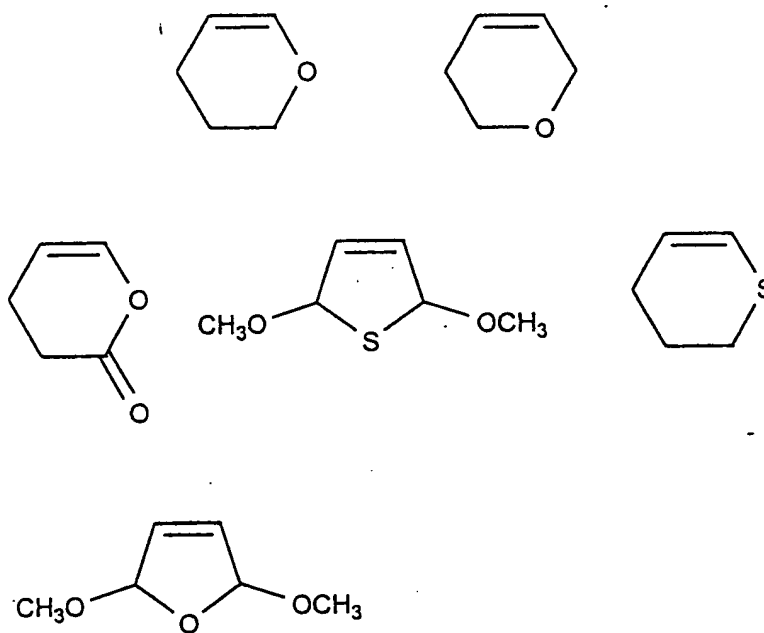
5 Polymers of the invention also may contain additional units such as cyano units, lactone units or anhydride units. For example, acrylonitrile or methacrylonitrile may be polymerized to provide pendant cyano groups, or maleic anhydride may be polymerized to provide a fused anhydride unit.

10 As discussed above, polymers of the invention are preferably employed in photoresists imaged at short wavelengths, particularly sub-200 nm such as 193 nm and 157 nm. Polymers also can be employed in photoresists imaged at higher wavelengths such as 248 nm. For such higher wavelength applications, the polymer may suitably contain aromatic units, e.g. polymerized styrene or hydrostyrene units.

15 Polymers of the invention can be prepared by a variety of methods. One suitable method is an addition reaction which may include free radical polymerization, e.g., by reaction of selected monomers to provide the various units as discussed above in the presence of a radical initiator under an inert atmosphere (e.g., N_2 or argon) and at
20 elevated temperatures such as about 70°C or greater, although reaction temperatures may vary depending on the reactivity of the particular reagents employed and the boiling point of the reaction solvent (if a solvent is employed). Suitable reaction solvents include e.g. tetrahydrofuran, ethyl lactate and the like. Suitable reaction temperatures for any particular system can be readily determined empirically by those skilled in the art based
25 on the present disclosure. A variety of free radical initiators may be employed. For example, azo compounds may be employed such as azo-bis-2,4-dimethylpentanenitrile. Peroxides, peresters, peracids and persulfates also could be employed.

Other monomers that can be reacted to provide a polymer of the invention can be identified by those skilled in the art. For example, to provide photoacid-labile units, suitable monomers include e.g. methacrylate or acrylate that contains the appropriate group substitution (e.g. tertiary alicyclic, t-butyl, etc.) on the carboxy oxygen of the ester group. Maleic anhydride is a preferred reagent to provide fused anhydride polymer units. Itaconic anhydride also is a preferred reagent to provide anhydride polymer units, preferably where the itaconic anhydride has purified such as by extraction with chloroform prior to polymerization. Vinyl lactones are also preferred reagents, such as alpha-butyrolactone.

Some suitable vinyl (endocyclic double bond) heterocyclic monomers that can be polymerized to provide polymers of the invention include the following:



Preferably a polymer of the invention will have a weight average molecular weight (Mw) of about 800 or 1,000 to about 100,000, more preferably about 2,000 to about 30,000, still more preferably from about 2,000 to 15,000 or 20,000, with a molecular weight distribution (Mw/Mn) of about 3 or less, more preferably a molecular

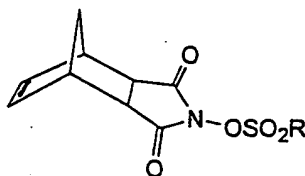
weight distribution of about 2 or less. Molecular weights (either Mw or Mn) of the polymers of the invention are suitably determined by gel permeation chromatography.

Polymers of the invention used in photoresist formulations should contain a sufficient amount of photogenerated acid labile ester groups to enable formation of resist relief images as desired. For instance, suitable amount of such acid labile ester groups will be at least 1 mole percent of total units of the polymer, more preferably about 2 to 50 mole percent, still more typically about 3 to 30 or 40 mole percent of total polymer units. See the examples which follow for exemplary preferred polymers.

As discussed above, the polymers of the invention are highly useful as a resin binder component in photoresist compositions, particularly chemically-amplified positive resists. Photoresists of the invention in general comprise a photoactive component and a resin binder component that comprises a polymer as described above.

The resin binder component should be used in an amount sufficient to render a coating layer of the resist developable with an aqueous alkaline developer.

The resist compositions of the invention also comprise a photoacid generator (i.e. "PAG") that is suitably employed in an amount sufficient to generate a latent image in a coating layer of the resist upon exposure to activating radiation. Preferred PAGs for imaging at 193 nm and 248 nm imaging include imidosulfonates such as compounds of the following formula:

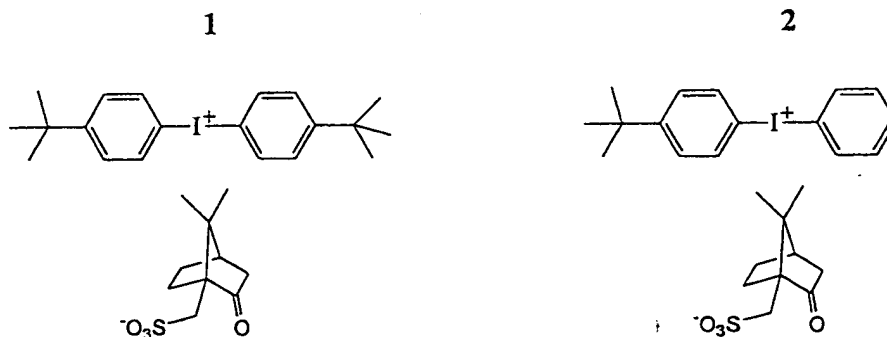


wherein R is camphor, adamantane, alkyl (e.g. C₁₋₁₂ alkyl) and perfluoroalkyl such as perfluoro(C₁₋₁₂alkyl), particularly perfluorooctanesulfonate, perfluorononanesulfonate

and the like. A specifically preferred PAG is N-[(perfluorooctanesulfonyl)oxy]-5-norbornene-2,3-dicarboximide.

Sulfonate compounds are also suitable PAGs, particularly sulfonate salts. Two
5 suitable agents for 193 nm and 248 nm imaging are the following PAGS 1 and 2:

10



Such sulfonate compounds can be prepared as disclosed in European Patent
15 Application 96118111.2 (publication number 0783136), which details the synthesis of
above PAG 1.

Also suitable are the above two iodonium compounds complexed with anions
other than the above-depicted camphorsulfonate groups. In particular, preferred anions
20 include those of the formula RSO_3^- where R is adamantane, alkyl (e.g. C_{1-12} alkyl) and
perfluoroalkyl such as perfluoro (C_{1-12} alkyl), particularly perfluorooctanesulfonate,
perfluorobutanesulfonate and the like.

Other known PAGS also may be employed in the resists of the invention.
25 Particularly for 193 nm imaging, generally preferred are PAGS that do not contain
aromatic groups, such as the above-mentioned imidosulfonates, in order to provide
enhanced transparency.

A preferred optional additive of resists of the invention is an added base, particularly tetrabutylammonium hydroxide (TBAH), or tetrabutylammonium lactate, which can enhance resolution of a developed resist relief image. For resists imaged at 193 nm, a preferred added base is a hindered amine such as diazabicyclo undecene or diazabicyclononene. The added base is suitably used in relatively small amounts, e.g. about 0.03 to 5 percent by weight relative to the total solids.

Photoresists of the invention also may contain other optional materials. For example, other optional additives include anti-striation agents, plasticizers, speed enhancers, etc. Such optional additives typically will be present in minor concentrations in a photoresist composition except for fillers and dyes which may be present in relatively large concentrations, e.g., in amounts of from about 5 to 30 percent by weight of the total weight of a resist's dry components.

The resists of the invention can be readily prepared by those skilled in the art. For example, a photoresist composition of the invention can be prepared by dissolving the components of the photoresist in a suitable solvent such as, for example, ethyl lactate, ethylene glycol monomethyl ether, ethylene glycol monomethyl ether acetate, propylene glycol monomethyl ether; propylene glycol monomethyl ether acetate and 3-ethoxyethyl propionate. Typically, the solids content of the composition varies between about 5 and 35 percent by weight of the total weight of the photoresist composition. The resin binder and photoactive components should be present in amounts sufficient to provide a film coating layer and formation of good quality latent and relief images. See the examples which follow for exemplary preferred amounts of resist components.

The compositions of the invention are used in accordance with generally known procedures. The liquid coating compositions of the invention are applied to a substrate such as by spinning, dipping, roller coating or other conventional coating technique.

When spin coating, the solids content of the coating solution can be adjusted to provide a desired film thickness based upon the specific spinning equipment utilized, the viscosity of the solution, the speed of the spinner and the amount of time allowed for spinning.

5 The resist compositions of the invention are suitably applied to substrates conventionally used in processes involving coating with photoresists. For example, the composition may be applied over silicon wafers or silicon wafers coated with silicon dioxide for the production of microprocessors and other integrated circuit components. Aluminum-aluminum oxide, gallium arsenide, ceramic, quartz, copper, glass substrates
10 and the like are also suitably employed.

 Following coating of the photoresist onto a surface, it is dried by heating to remove the solvent until preferably the photoresist coating is tack free. Thereafter, it is imaged through a mask in conventional manner. The exposure is sufficient to effectively
15 activate the photoactive component of the photoresist system to produce a patterned image in the resist coating layer and, more specifically, the exposure energy typically ranges from about 1 to 100 mJ/cm², dependent upon the exposure tool and the components of the photoresist composition.

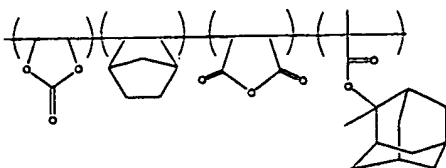
20 As discussed above, coating layers of the resist compositions of the invention are preferably photoactivated by a short exposure wavelength, particularly a sub-300 and sub-200 nm exposure wavelength. As discussed above, 193 nm is a particularly preferred exposure wavelength. 157 nm also is a preferred exposure wavelength. However, the resist compositions of the invention also may be suitably imaged at higher wavelengths.
25 For example, a resin of the invention can be formulated with an appropriate PAG and sensitizer if needed and imaged at higher wavelengths e.g. 248 nm or 365 nm.

Following exposure, the film layer of the composition is preferably baked at temperatures ranging from about 70°C to about 160°C. Thereafter, the film is developed. The exposed resist film is rendered positive working by employing a polar developer, preferably an aqueous based developer such as quaternary ammonium hydroxide solutions such as a tetra-alkyl ammonium hydroxide solution; various amine solutions preferably a 0.26 N tetramethylammonium hydroxide, such as ethyl amine, n-propyl amine, diethyl amine, di-n-propyl amine, triethyl amine, or methyldiethyl amine; alcohol amines such as diethanol amine or triethanol amine; cyclic amines such as pyrrole, pyridine, etc. In general, development is in accordance with procedures recognized in the art.

Following development of the photoresist coating over the substrate, the developed substrate may be selectively processed on those areas bared of resist, for example by chemically etching or plating substrate areas bared of resist in accordance with procedures known in the art. For the manufacture of microelectronic substrates, e.g., the manufacture of silicon dioxide wafers, suitable etchants include a gas etchant, e.g. a halogen plasma etchant such as a chlorine or fluorine-based etchant such as Cl_2 or CF_4/CHF_3 etchant applied as a plasma stream. After such processing, resist may be removed from the processed substrate using known stripping procedures.

All documents mentioned herein are incorporated herein by reference. The following non-limiting examples are illustrative of the invention.

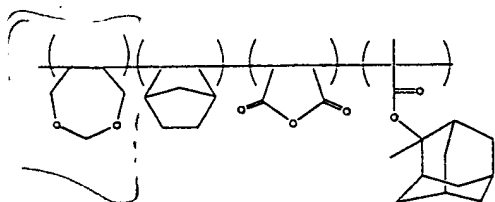
Example 1: Synthesis of polymer containing vinylene carbonate.



Polymer of the above structure (units in the following molar amount as appearing from left to right: 20/10/30/40) was synthesized as follows.

A mixture of 2-methyladamantanyl methacrylate (15.64 g), maleic anhydride (4.91g), norbornene (1.57g), vinylene carbonate (2.87g), and dimethyl-2,2'-azodiisobutyrate (0.77g, 2 mol% of total monomers) in 25g of dioxane was placed in a round-bottomed flask fitted with a reflux condenser and nitrogen purge. The flask was then placed in a pre-heated 85°C oil bath. This reaction mixture was stirred at this temperature for 24 hours, under nitrogen. After cooling the reaction mixture to room temperature, the solution was diluted to 33% (wt/wt) with dioxane. The polymer was isolated by precipitation into 1 L of isopropyl alcohol, then filtered off and washed with an additional 100 ml of isopropyl alcohol. Finally, the polymer was dried in a vacuum oven at 40°C for overnight, yield =60%.

Example 2: Synthesis of polymer containing 4,7-Dihydro -1,3 dioxepin.



A polymer of the above structure (units in the following molar amount as appearing from left to right: 20/10/30/40) was synthesized as follows.

A mixture of 2-methyladamantanyl methacrylate (15.35g), maleic anhydride (4.82g), norbornene (1.54g), 4,7-dihydro -1,3 dioxepin (3.28g), and dimethyl-2,2'-azodiisobutyrate (0.76g, 2 mol% of total monomers) in 25g of dioxane was placed in a round-bottomed flask fitted with a reflux condenser and nitrogen purge. The flask was then placed in a pre-heated 85°C oil bath. This reaction mixture was stirred at this

temperature for 24 hours, under nitrogen. After cooling the reaction mixture to room temperature, the solution was diluted to 33% (wt/wt) with dioxane. The polymer was isolated by precipitation into 1 L of isopropyl alcohol, then filtered off and washed with an additional 100 ml of isopropyl alcohol. Finally, the polymer was dried in a vacuum oven at 40°C for overnight, yield =62%.

Example 3: Photoresist preparation and lithographic processing.

A photoresist of the invention is prepared by mixing the following components with amount expressed as weight percents based on total weight of the resist composition:

| <u>Resist components</u> | <u>Amount (wt. % based on total solids)</u> |
|--------------------------|---|
| Resin binder | 28.2 |
| Photoacid generator | 0.52 |
| Basic additive | 0.03 |
| Surfactant | 0.03 |

The resin binder is the polymer of Example 2 above. The photoacid generator is triphenylsulfonium triflate. The basic additive is triisopropanol amine. The surfactant is Silwet (Dow Chemical). Those resist components were formulated at 16 wt. % solids in a solvent of 2-heptatone.

The formulated resist composition is spin coated onto HMDS vapor primed 4 inch silicon wafers and softbaked via a vacuum hotplate at 130°C for 60 seconds. The resist coating layer is exposed through a photomask at 193 nm using an ISI microstepper, and then the exposed coating layers are post-exposure baked (PEB) at about 130°C. The coated wafers are then treated with alkaline aqueous developer (0.26N aqueous tetramethylammonium hydroxide solution to develop the imaged resist layer and provide a relief image.

Examples 4-7: Syntheses of monomers useful in preparation of polymers of the invention.

Example 4: EtTCD Methacrylate monomer synthesis

8-ethyl-8-tricyclodecanylmethacrylate (EtTCD methacrylate) was prepared as following using the reagents and amounts thereof as specified in the following table.

| Material | Amt (g) | Amt (ml) | Moles | Source |
|-----------------------------|---------|----------|-------|---------|
| TCD | 150.22 | | 1.00 | TCI |
| Ethylmagnesiumchloride(25%) | 390.85 | ~379.5 | ~1.10 | ACROS |
| Methacryloyl chloride | 120.22 | ~112.4 | ~1.15 | Aldrich |
| Tetrahydrofuran | 480 | 540 | | Aldrich |

All reaction glassware was dried in the oven overnight at 100°C. The glassware was set up and cooled under a stream of nitrogen. The reaction was carried out under a blanket of nitrogen.

To a 2L 3N-RB flask fitted with a gas inlet, thermometer, overhead stirrer and a rubber septum was added 400g of ethylmagnesium chloride, 25 wt% solution in tetrahydrofuran (clear, amber solution) via a double tipped needle using nitrogen pressure. The mixture was cooled to -25 to -30°C using a dry ice/isopropanol bath. While the ethylmagnesium chloride solution was cooling the 153.6g of tricyclodecane (TCD) was dissolved in 480g of tetrahydrofuran. To a 1L 3N-RB flask equipped with a gas inlet, glass stopper and a rubber septum was added the 153.6g of TCD. The anhydrous, inhibitor free tetrahydrofuran was transferred to the 1L flask via a double tipped needle using nitrogen pressure. When the ethylmagnesium chloride was at -25 to -30°C, the TCD/THF solution was transferred over a 2hr period to the 2L 3N-RB flask containing the ethylmagnesium chloride via a double tipped needle using nitrogen pressure. The cooling bath was removed and the reaction mixture was stirred for 2 hr. After stirring for 2 hr the mixture was again cooled to -25 to -30°C using a dry ice/isopropanol bath. The methacryloyl chloride (120.22g) was then added dropwise over a 1 hour period using a 125ml pressure equalizing dropping funnel. The reaction was allowed to come to room

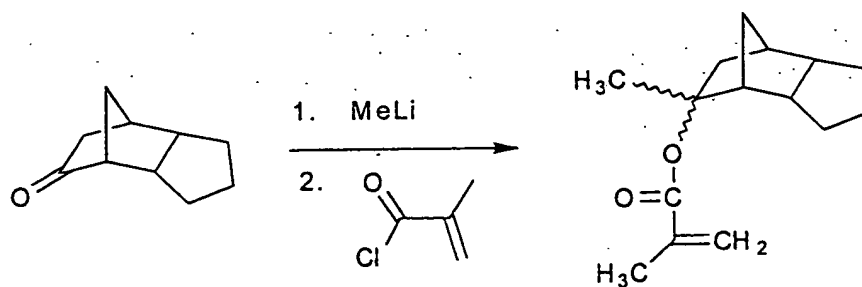
temperature with overnight stirring. A white precipitate developed from the clear amber colored reaction solution. Water (DI) was added until all of the salts had dissolved (~500ml) and two distinct layer were seen. The layers were separated and the organic (upper) layer was washed with 2x400ml DI water then dried over magnesium sulfate. The THF was removed leaving 258g of an orange oil. The orange oil was dissolved in 400g of hexane then passed through a 400g silica gel plug which had been pre-conditioned with hexane. The silica was washed with hexane until all of the product was removed (spot filtrate on a TLC plate and illuminate under short UV). The hexane was removed leaving 202.8g of an clear, colorless oil. Theoretical yield: 248.4g; yield: 81.6%

Example 5: Synthesis of Norbornene Valerolactone

A solution of valerolactone (50.1 g) in 150 mL of anhydrous THF was placed in a three-neck-bottomed flask at -78°C (Dry Ice/acetone). To it, solution of LDA (250 mL, 2M) in 250 mL anhydrous THF was added dropwise. The reaction mixture was stirred at this temperature for 4 hours. Then, the thermal cracking of paraformaldehyde (36.94 g, excess) was bubbled into the reaction mixture. After the paraformaldehyde was all cracked, the reaction mixture was stirred at the same bath and stirred for overnight. Then, the solvent was removed by rotary pump and the residue was added 500 mL CH_2Cl_2 and washed with NaHCO_3 (aq, sat.) and water several times (3 x 500mL). The combination organic solvent was dried over MgSO_4 and the solvent was removed by rotary pump. The desired product was distilled under vacuum ($135\text{-}140^{\circ}\text{C}/8\text{mmHg}$)

The methylene-valerolactone was dissolved in dichloromethane and freshly cracked cyclopentadiene was added. The reaction mixture was stirred at room temperature for 3 hours, then heated to 40°C , and held at 40°C overnight. The reaction mixture was then slowly cooled to room temperature. The methylene chloride was removed under reduced pressure, leaving an oil. The crude oil was then distilled under reduced pressure to afford pure product.

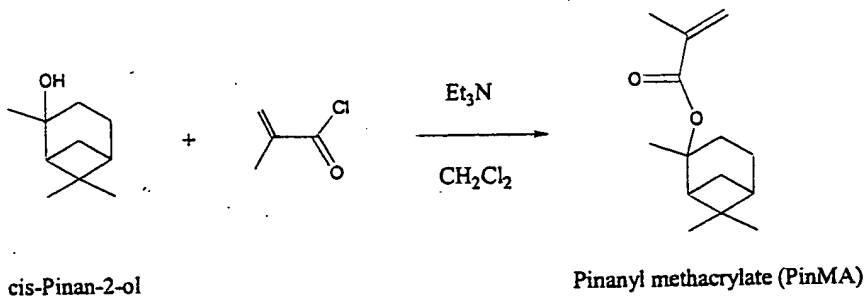
Example 6: Synthesis of 8-methyltricyclodecanyl methacrylate:



A solution of 125 ml of 1.4 M methyl lithium (in ethyl ether) in 100 ml of hexane
 5 was decanted into a three neck round-bottom flask at an ice-water bath. To it, a solution
 of 24.00 g of tricyclo[5.2.1.0]decan-8-one in hexane was added dropwise. After addition,
 the reaction mixture was stirred for 4 hours at 0°C. Then, a solution of 16 ml of
 methacroyl chloride in 100 ml of hexane was added dropwise at 0°C. After addition, the
 reaction mixture was stirred at the same bath for overnight (16 hours). After filtering the
 10 white salts, the organic layer was washed with water three times (3 x 300 ml). Then, the
 washed organic layer was dried over anhydrous MgSO₄. The organic solvent was
 removed by a rotary pump to give the crude title monomer (23.5 g). The monomer was
 purified by a flash column chromatography (purity >98%, silica gel with hexane). ¹H
 NMR: 6.05 (1H), 5.50 (1H), 1.95 (3H), 1.65 (3H), 2.25-0.85 (14H).

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Example 7: Synthesis of pinanyl methacrylate



Materials used:

| | Amount Charged | Moles | Source |
|---------------------------------|----------------|-------|-------------------------------|
| cis-Pinan-2-ol | 15.43 g | 0.10 | Fluka |
| Et ₃ N | 12.14 g | 0.12 | Aldrich, distilled before use |
| Methacryloyl chloride | 13.07 g | 0.125 | Aldrich, distilled before use |
| CH ₂ Cl ₂ | 230 mL | | Aldrich, dried and distilled |

Procedure:

- 5 All reaction glassware and needles were dried and flushed with dry N₂ before use and the reaction was carried out under nitrogen atmosphere.
- 1) Into a 500 mL 3-neck round-bottom-flask equipped with an addition funnel and a magnetic stirrer were added 15.43 g of cis-pinan-2-ol and 200 mL of dry CH₂Cl₂ (Stirred over CaH₂ overnight, then distilled and stored over activated molecular
10 sieves). The resulting colorless solution was cooled with an ice-water bath.
- 2) Triethylamine (12.14 g) was added through the addition funnel to the cooled CH₂Cl₂ solution over 10 min. After added, the resulting solution was kept in a dry-ice/acetone bath (-67 °C).
- 3) A CH₂Cl₂ (30 mL) solution of methacryloyl chloride (13.07 g) was added dropwisely
15 over 20 min. The resulting orangish suspension was allowed to warm to room temperature and stirred for 2 h.
- 4) The chloride salts were filtered off. The filtrate was washed with saturated Na₂CO₃ solution (2 x 200 mL), then DI water (3 x 200 mL) , and dried over anhydrous MgSO₄.
- 20 5) The slightly yellow CH₂Cl₂ solution was concentrated on a rotary evaporator (bath temperature kept below 35°) to yield a clear slightly yellow liquid product. Yield = 79%. The product was judged pure by NMR.

The foregoing description of the invention is merely illustrative thereof, and it is understood that variations and modification can be made without departing from the spirit or scope of the invention as set forth in the following claims.

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